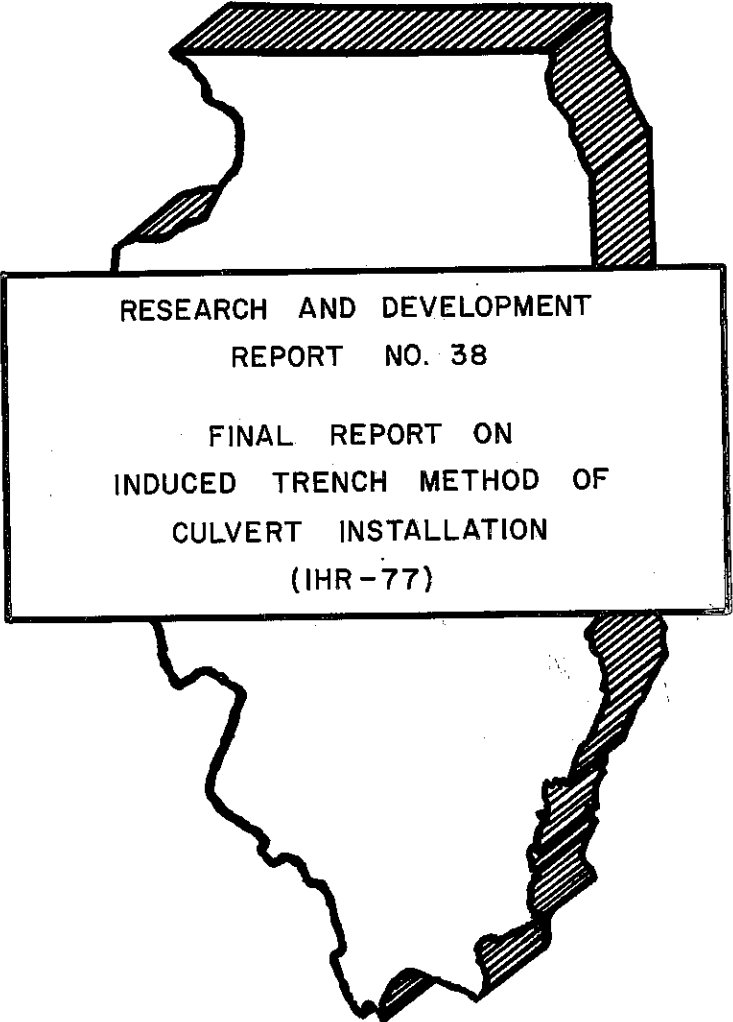


STATE OF ILLINOIS
DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
DIVISION OF HIGHWAYS



RESEARCH AND DEVELOPMENT
REPORT NO. 38

FINAL REPORT ON
INDUCED TRENCH METHOD OF
CULVERT INSTALLATION
(IHR-77)



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State of Illinois
DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
Division of Highways
Bureau of Research and Development

FINAL REPORT
ON
INDUCED TRENCH METHOD OF CULVERT INSTALLATION

by

R. K. Taylor

Project THR-77

A Research Project Conducted by
Illinois Division of Highways and
American Concrete Pipe Association
in Cooperation with
U.S. Department of Transportation
Federal Highway Administration

The opinions, findings, and conclusions expressed in this report are those of the Illinois Division of Highways and not necessarily those of the Federal Highway Administration.

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INDUCED TRENCH METHOD OF CULVERT INSTALLATION

ABSTRACT

The induced trench (imperfect trench) method of culvert installation is used to reduce the loads on a culvert under a high fill. Although the method has been used successfully with concrete pipe under some unusually high fills, the magnitude of the reduction in load achieved by the induced trench has not been clearly established. This research project was initiated to evaluate the settlement ratio and to compare the measured loads acting on the culvert with theoretical loads. Such an evaluation would be useful for establishing design criteria for this type of construction.

This report includes a description of the construction and instrumentation of a 48-inch reinforced concrete pipe culvert installed by the induced trench method. Settlement data were collected and analyzed to determine the settlement ratio for this type of installation. In addition, the pressures acting at the top and sides of the pipe were measured and compared with theoretical loads determined by Marston's theory of loads on underground conduits.

The results of this research indicate that the range of empirical values that have been recommended for the settlement ratio for the induced trench is reasonable for this type of culvert under 30 feet of fill. A comparison of the measured loads acting on the culvert with theoretical loads indicates that the load theory is somewhat conservative.

SUMMARY

The construction of underground drainage structures in accordance with the high safety standards developed for the Interstate Highway System has led to increased costs for culvert installations. One proposed method of reducing culvert costs is the induced trench procedure, formerly known as the imperfect trench method, developed by the late Dean Marston, of Iowa State College. Although the method is known to result in a substantial reduction in loads on a culvert, the magnitude of the load reduction has not been clearly established.

An important parameter used in the analysis of the induced trench is the settlement ratio. This ratio indicates the amount of differential settlement occurring between the column of soil directly above the culvert and the adjacent soil and is used to determine the magnitude of the loads acting on the culvert. If the settlement ratio for an induced trench installation can be predetermined, the working loads acting on the culvert can be estimated with reasonable accuracy. Since current knowledge of the settlement ratio is based on limited experimental proof, an evaluation of the ratio from a number of field installations is needed to establish criteria for designing culverts constructed by the induced trench method.

This research project was undertaken to evaluate the settlement ratio and to study the top and lateral loads on a 48-inch reinforced concrete pipe culvert under 30 feet of fill installed by the induced trench method. The project was conducted as a joint venture of the Illinois Division of Highways and the American Concrete Pipe Association with the cooperation of the Federal Highway Administration. Soil Testing Services, Inc., Northbrook, Illinois, acting as an agent of the American Concrete Pipe Association, installed the research instruments and collected the data.

The values of the settlement ratio determined during this research project are near the limits of the range of empirical values of -0.3 to -0.5 that have been recommended for the induced trench method of installation. Two of the three instrumented locations along the length of the culvert yielded values of the settlement ratio of -0.25 and -0.45. At the third location the recorded settlement ratio of -0.8 appeared to be unreliable because of discrepancies in the data.

Based on the results of this research, a range of values for the settlement ratio from -0.25 to -0.50 appears to be reasonable for the induced trench method of construction when the height of fill above the culvert is approximately 30 feet. However, further studies should be made of other field installations incorporating different sizes of culverts placed under various fill heights before concluding that this range of values for the settlement ratio is correct for all such installations.

Loads determined from pressures measured at the top of the pipe culvert were equal to about 50 percent of the theoretical loads determined from Marston's formula. The measured pressures of 1 to 2 psi at the sides of the pipe appear to be low for this type of installation. More data from similar research projects are needed to evaluate the accuracy of the load theory. At the present time it is recommended that the theory, which appears to be conservative, continue to be used without adjustment.

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INDUCED TRENCH METHOD OF CULVERT INSTALLATION

INTRODUCTION

The construction of underground drainage structures in accordance with high safety standards such as those developed for the Interstate Highway System has led to increased costs for culvert installations. The relatively flat highway profiles result in high earth fills which require longer culverts capable of supporting heavier overburden loads. Ways are continually being sought to reduce the cost of the culverts while still maintaining adequate structural performance.

One proposed method of reducing culvert costs is the induced trench procedure, formerly known as the imperfect trench method, developed by the late Dean Marston of Iowa State College. Several states have reported a large reduction of loads on culverts under high fills when utilizing this method of construction. Although the reduction in load is known to be substantial, the magnitude of the load reduction has not been clearly established.

The procedure for constructing the induced trench is summarized as follows:

1. The embankment is thoroughly compacted around and above the pipe to a height of about one pipe diameter above the top of the conduit.
2. A trench equal in width to the outside diameter of the pipe is constructed directly over the culvert by removing a prism of material from the compacted fill.
3. The trench is refilled with a loose compressible material.
4. The remainder of the embankment is completed in the usual manner.

The purpose of the induced trench filled with compressible material is to insure that the column of soil directly above the culvert will settle downward relative to the adjacent soil within the embankment. The differential movement results in the development of shearing forces acting upward on the interior prism

of soil which provide partial support to the column of soil above the culvert. The magnitude of the relative movement determines the amount of load that is transferred to the adjacent soil and the amount of load that is supported by the culvert. A parameter which is used to indicate the magnitude of the relative movement is the settlement ratio. If the settlement ratio is known or can be estimated within reasonable limits, the design loads acting on the culvert can be predicted with a greater degree of accuracy.

Although the induced trench has been successfully used with concrete pipe under some unusually high fills, opportunities to evaluate the settlement ratio under field conditions have been limited. Since current knowledge of the settlement ratio is based on limited experimental proof, an evaluation of the ratio from a number of field installations would greatly help to establish design criteria for the induced trench method of construction.

In order to investigate the settlement ratio and to compare measured loads with theoretical values for a typical field installation, the Illinois Division of Highways in 1961 selected a site for an experimental culvert installation by the induced trench method on Interstate 74 in Henry County two miles south of Green Rock. The site is identified as Station 892+25, Section 37-1HB-1, FAI Route 74. A 48-inch Type 4 reinforced concrete pipe culvert was placed at the location. The experimentation was undertaken as a joint venture with the American Concrete Pipe Association in cooperation with the Federal Highway Administration. Soil Testing Services, Inc., Northbrook, Illinois, acting as an agent of the American Concrete Pipe Association, installed the research instruments and collected the data. All construction operations, installation of research instruments, and collection of data were in accordance with "Specifications for Experimental Induced Trench Installation" (Appendix A) developed jointly by the American Concrete Pipe Association and the Illinois Division of Highways for this project.

This report describes the construction and instrumentation of the induced trench installation along with an analysis of the data compiled and the conclusions derived from the data. Although the measured loads at this installation appear to be considerably less than the corresponding theoretical loads, the results of this research indicate that the range of empirical values of -0.3 to -0.5 that have been recommended for the settlement ratio for the induced trench is reasonable.

RESEARCH OBJECTIVES

The primary objective of this research was to determine the settlement ratio used in estimating the loads on conduits installed by the induced trench method of construction. From settlement data collected during this study realistic values of settlement ratios were determined for the induced trench constructed under the specific conditions present at the test site. These data, in addition to other information from a number of similar installations with varying fill heights and different culvert sizes, will eventually provide the means for more accurately predicting the settlement ratio for the design of culverts constructed by the induced trench method.

The secondary objective of this research was to determine the vertical and lateral loads applied to the culvert during and after construction of the embankment. Although the current theories on loads on pipe culverts are considered accurate, the measurement of soil pressures acting on the culvert would serve to confirm existing theories.

THEORETICAL CONCEPTS

The purpose of the induced trench is achieved as the column of soil above the culvert settles downward relative to the adjacent compacted soil. The relative movement generates shearing forces which act upward on the interior prism of soil

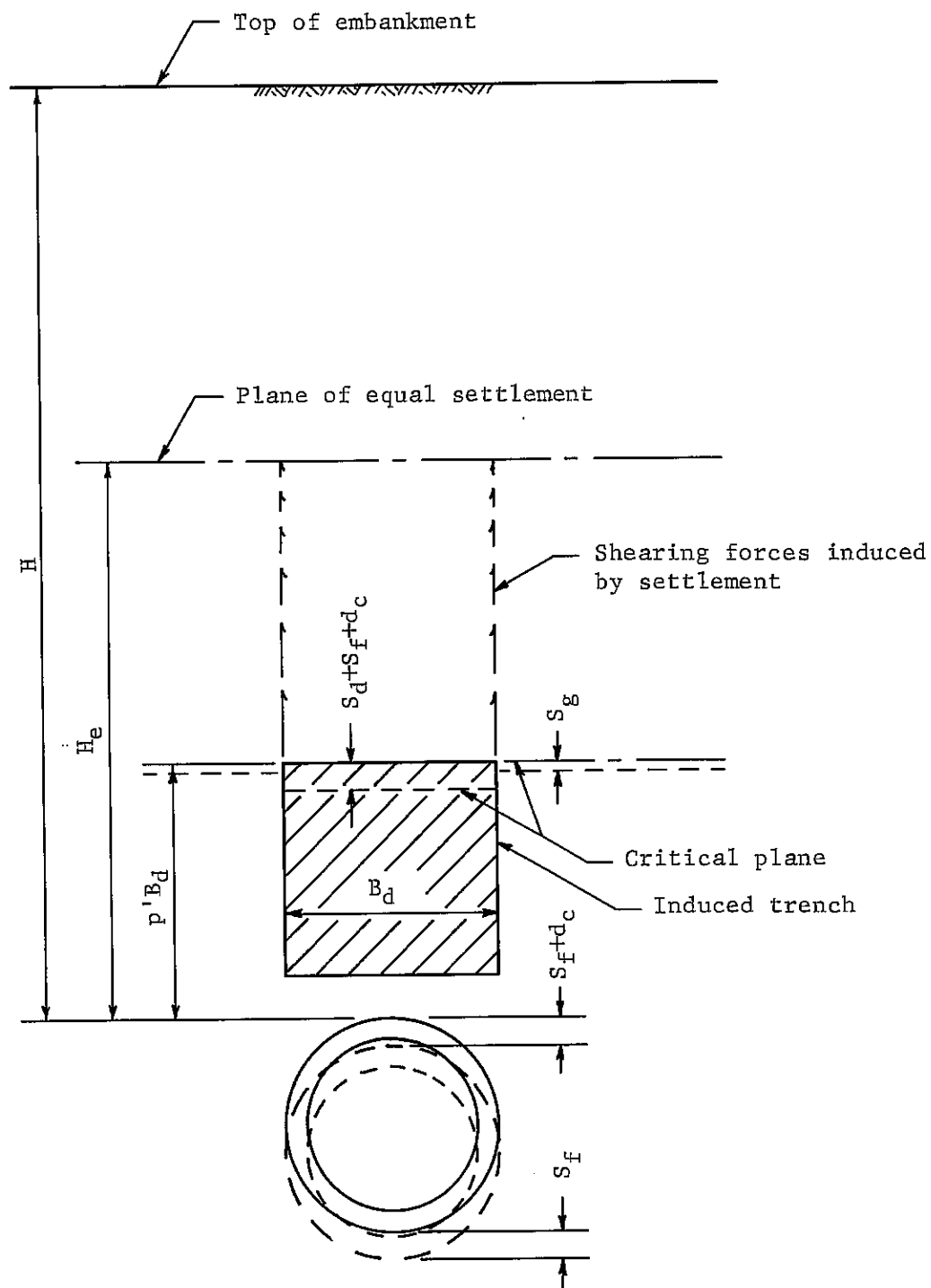


Figure 1. Settlements which influence loads on induced trench conduits.

$$(1) \quad r_{sd} = \frac{S_g - (S_d + S_f + d_c)}{S_d}$$

Where r_{sd} = settlement ratio

S_g = settlement of the compacted embankment at the level of the top of the trench and adjacent to the sides of the trench

S_d = deformation of fill from the top of the pipe to the top of the trench

S_f = settlement of flow line of conduit

d_c = shortening of the vertical dimension of the pipe

Figure 1 illustrates the location of the various factors used in Equation 1 to compute the settlement ratio. During this study all of the factors in the formula were measured directly in the field with the exception of S_d . S_d was determined by subtracting the measured values of S_f and d_c from the total settlement of the critical plane measured as $(S_d + S_f + d_c)$.

Once the settlement ratio is established, charts have been developed by Spangler¹ which facilitate the computation of the theoretical loads on the conduit as determined by the following formula:

$$(2) \quad W_c = C_n w B_d^2$$

Where W_c = load per linear foot of conduit

C_n = a load coefficient which is a function of the ratio of the height of fill to the width of ditch H/B_d ; of the projection ratio p' ; of the settlement ratio r_{sd} ; and of the coefficient of internal friction μ

1. M. G. Spangler, Soil Engineering (second edition; Scranton, Pennsylvania: International Textbook Company, 1960), p. 409.

w = unit weight of backfill

B_d = width of trench

In his derivation of the load theory for underground conduits, Marston pointed out that the influence of the coefficient of internal friction (μ) of the fill material is relatively minor and, therefore, the product of Rankine's lateral pressure ratio (K) and the coefficient of internal friction may be safely assumed equal to 0.13 for the induced trench. Based on this assumption, Spangler's charts relate the load coefficient to the parameters used to analyze the induced trench (Figure 2). A different chart is used for each value of the projection ratio. Only the chart for a projection ratio of 1.0 is included in this report since the condition represents the case under study. Once the projection ratio and the H/B_d ratio are determined and the settlement ratio is estimated, the proper value of the load coefficient is found from the chart.

The chart may also be used to estimate the distance from the top of the pipe to the plane of equal settlement. The curve indicating the complete ditch condition represents the case of relative settlement occurring throughout the height (H) of the embankment. The point where the ray line for a given settlement ratio intersects the curve for the complete ditch condition indicates a value for the ordinate H/B_d where H now becomes equal to H_e which is the distance from the top of pipe to the plane of equal settlement.

RESEARCH INSTRUMENTATION

The instrumentation used to measure the required settlements consisted of settlement platforms with vertical reference rods located in groups of three beneath the median and under each outside shoulder (Figures 3 and 4). All settlement plates were placed in the plane of the top of the induced trench six feet

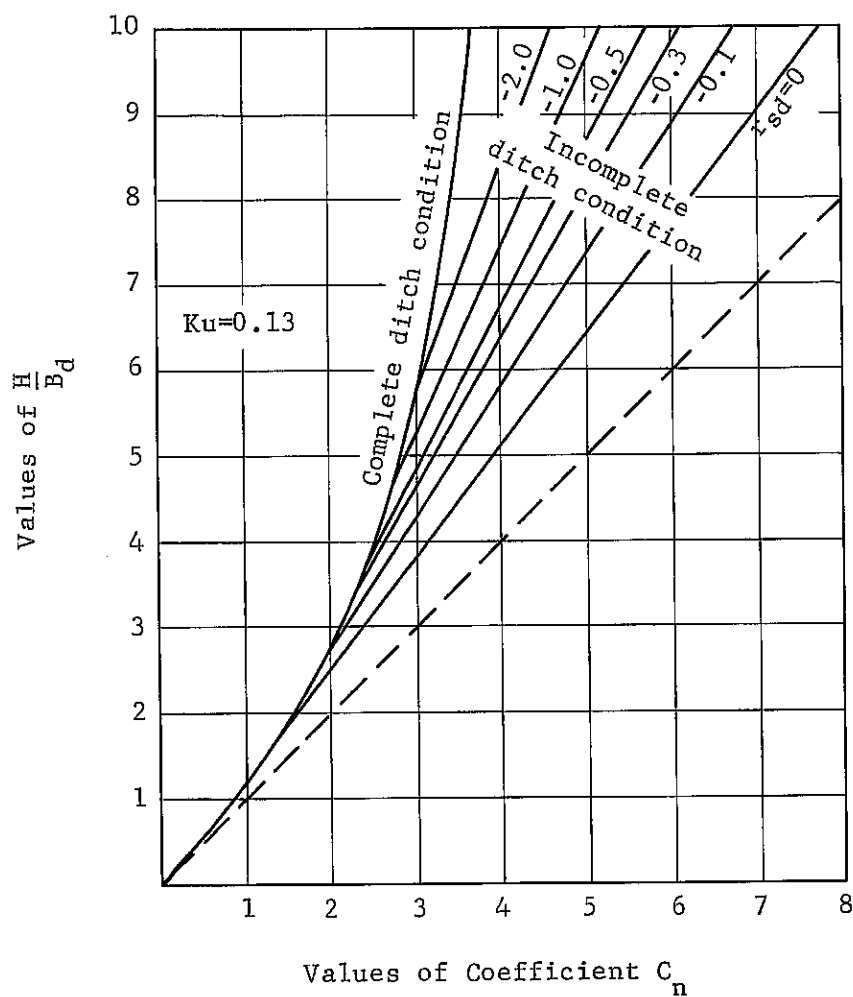


Figure 2. Diagram for coefficient C_n for induced trench conduit when $p'=1.0$.

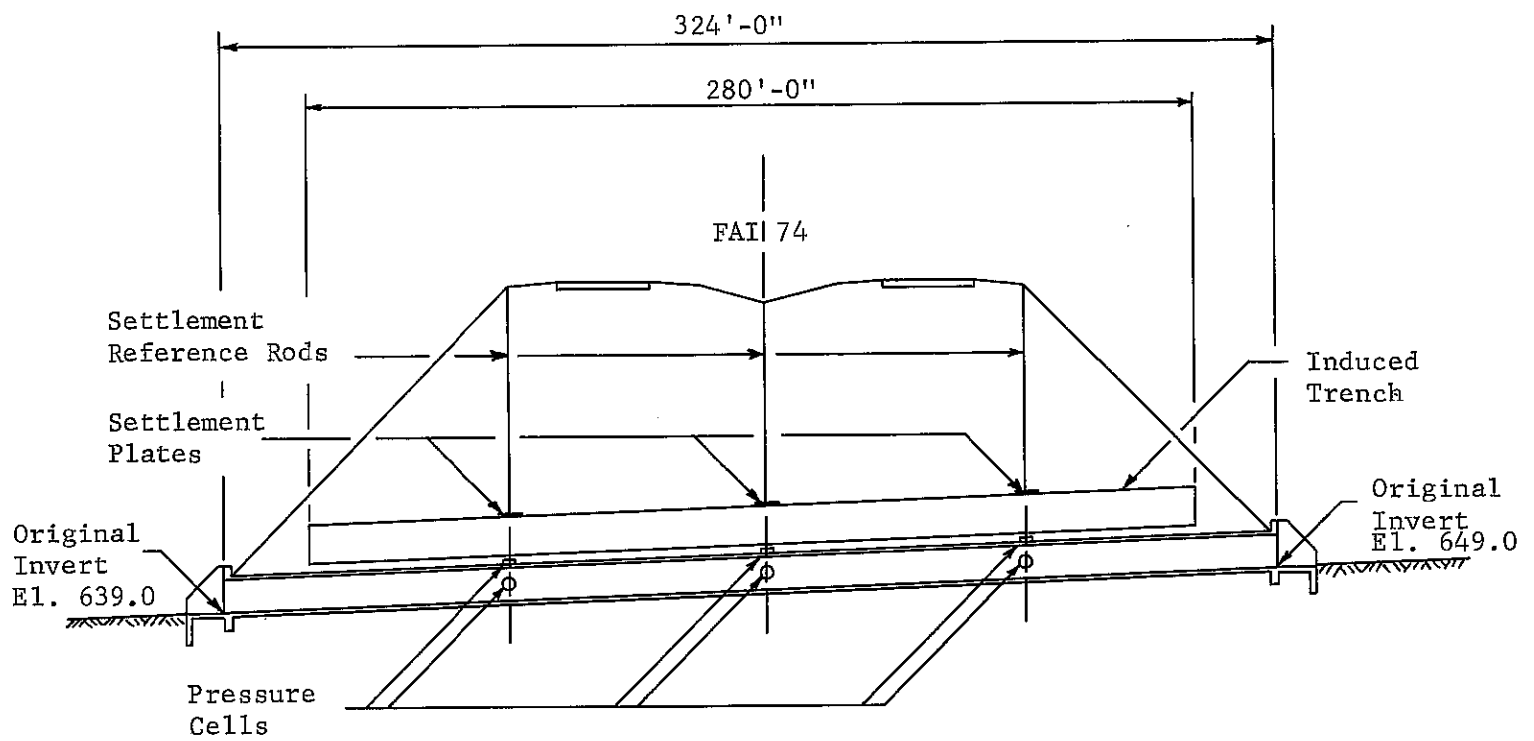


Figure 3. Location of pressure cells and settlement plates with reference rods.

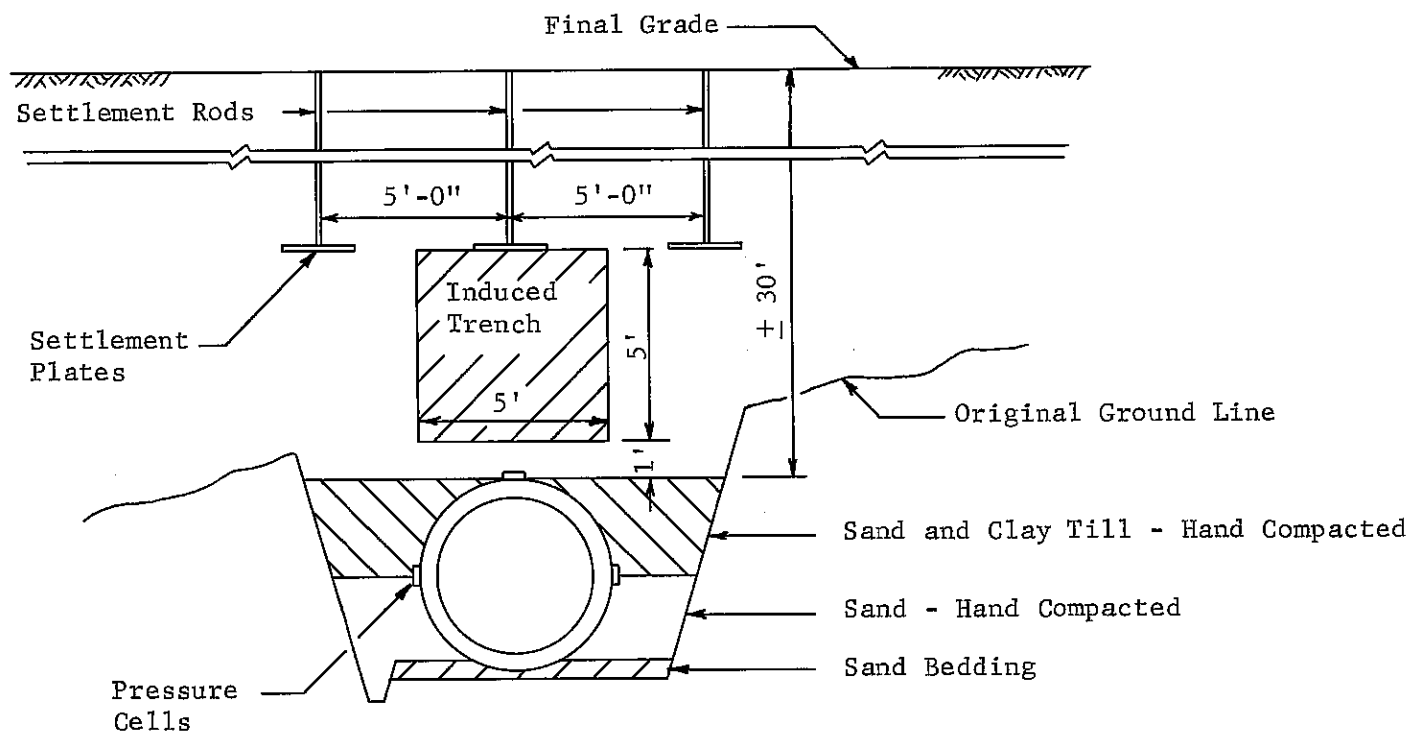


Figure 4. Typical cross section of induced trench.

above the top of the culvert pipe. One platform of each group was centered over the induced trench directly above the culvert centerline. This platform was used to measure values of $(S_d + S_f + d_c)$. The other two plates were located adjacent to each side of the trench at a distance of approximately five feet from the centerline of the culvert. The average measured settlement of these two plates was used to determine S_g . The platforms consisted of 24-inch square steel plates 1/4-inch thick with five-foot lengths of 1/2-inch steel pipe welded to the center of the plates. As the fill height was increased, additional five-foot extensions of 1/2-inch pipe were added (Figures 5 and 6).

Changes in culvert diameter were measured with an extensometer consisting of an Ames dial graduated in 0.001-inch increments fastened securely to one end of a steel rod (Figure 7). In order to insure that the extensometer would be at the same precise location each time that the pipe deformation was measured, reference points were established inside the pipe at the same locations along the culvert where the settlement plates and pressure cells were placed.

To measure invert elevations at the three locations of instrumentation, it was necessary to turn a vertical angle with a transit since the grade of the culvert was too steep to permit the use of a horizontal line of sight.

The pressure cells used to measure the earth pressure against the pipe were originally designed to measure pore pressures under earth dams. Their selection for use in this research was based on their resistance to damage from moisture, which makes them suitable for an extended study of pressure under a high fill.

Each cell consists of a sealed hollow plastic dish flat on one side and slightly convex on the other side. The cell is about eight inches in diameter, one inch deep at the edge, and 1 1/2 inches deep at the center. The interior of the cell is filled with oil having a very low viscosity. Suspended in the oil is



Figure 5. Installation of settlement plates.

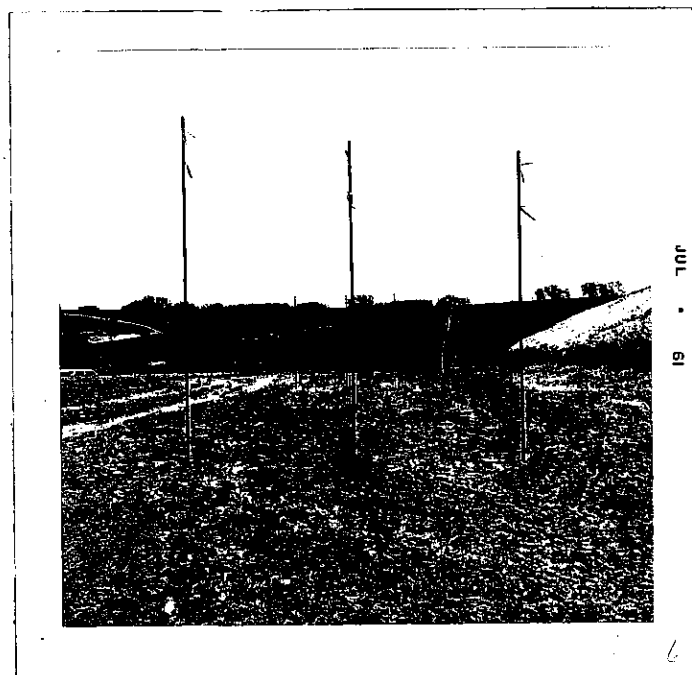


Figure 6. Steel pipe reference rods.



Figure 7. Extensometer used to measure inside pipe diameters.

a thin plastic envelope about four inches in diameter. Connected to the envelope at diametrically opposite points are 1/8-inch plastic tubes which lead out of the cell and are then brought together and threaded through a single large plastic tube for protection.

The sides of the cell are sufficiently flexible so that soil pressure applied to the outside of the cell is transmitted to the oil inside the cell. One of the 1/8-inch plastic tubes leading out of the cell is connected to a cylinder of compressed gas. Compressed nitrogen was used rather than compressed air to avoid condensation in the system. A regulating valve controls the flow of gas into the envelope which is held closed by the oil pressure until sufficient gas pressure develops to open the envelope and allow the gas to exhaust through the opposite tube.

Each cell is calibrated to give the external pressure if the applied gas pressure and the rate of flow of gas through the cell is known. A portable console containing the compressed gas cylinder, valves, and pressure gages was used to obtain readings.

The pressure cells were installed at the top and springlines of the culvert beneath the median and under the two outside shoulders (Figures 8 and 9). The pressure cells were attached to the outside of the culvert pipe when the top of the compacted embankment was one foot above the top of the pipe. Small pits were dug down to the cell locations at the top and springlines of the pipe. A flat mortar pad was formed at each cell location, and the cell was attached to the flat surface by an epoxy glue. The exposed face of each cell was covered with a two-inch layer of AM-9 chemical grout of such proportions as to insure a permanent gelatinous consistency. The 1/8-inch tubes were brought together and encased in a larger protective tube which conducted them through a lift hole into the barrel and out the end of the culvert where the pressure metering instrument could be attached. After installation of the pressure cells, the installation pits were carefully backfilled and compacted with pneumatic hand tampers.

CONSTRUCTION

Construction of the induced trench installation began in May 1961 and was completed in October 1961. Work was interrupted several times by wet weather. The culvert is located on a local channel change parallel to and under the base of a 30-foot high ridge. The entire culvert length of 324 feet is in cut except for the extreme downstream end which meets the natural channel.

The soil material is generally a compact clay till with a few stone fragments up to several inches in diameter. The uphill shoulder of the cut consists of a



Figure 8. Pressure cell before installation.



Figure 9. Pressure cell installed at springline.

mottled yellow silty clay loam over gravelly clay till. The downhill shoulder of the cut contains some black organic soils associated with the valley floor.

The maximum depth of cut at the centerline was about eight feet; the average depth was about six feet. The average width of excavation in the plane of the top of the pipe was about 11 feet; the average width at the flow line was about eight feet. The cut slopes were fairly smooth and well centered about the culvert centerline.

A six-inch compacted bed of sand was placed throughout the bottom of the cut to provide a firm base over the slightly muddy and gravelly bottom (Figure 10). A small ditch was dug at one side of the bottom of the cut for drainage during the placement of the pipe.

After the pipe was placed, sand backfill was carried up to the springlines and compacted with pneumatic hand tampers (Figure 11).

The backfill material from the springlines to top of pipe consisted of cut material admixed with waste sand from the previous operation. The use of pneumatic hand tampers was continued up to six inches below top of pipe. From six inches below to six inches above top of pipe, compaction was effected by driving a rubber tired four wheel tractor back and forth along the pipe (Figure 12). After the compacted cover over the pipe reached six inches, conventional sheepfoot rollers were used. When the compacted cover reached one foot, construction operations were halted to permit installation of the pressure cells.

After the pressure cells were installed and the installation pits were refilled and compacted by pneumatic hand tampers, the fill was completed to a level six feet above top of pipe. At that point a five-foot wide by five-foot deep by 280-foot long trench was excavated by backhoe directly over the culvert pipe. The trench was refilled by bulldozer with loose topsoil containing some sod and a few cornstalks (Figure 13). Density of the trench material varied from 51 to 56 percent of the



Figure 10. Six-inch compacted sand bed.

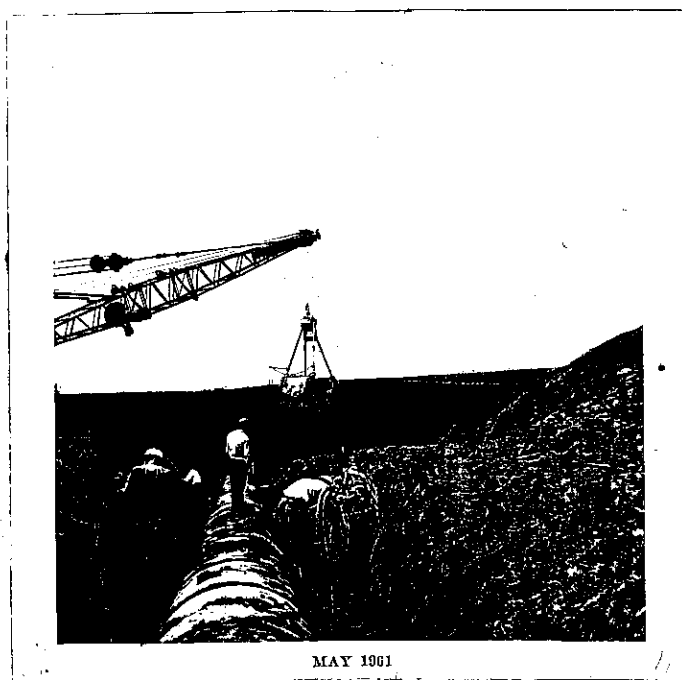


Figure 11. Compacting sand backfill up to springlines with pneumatic hand tampers.



Figure 12. Compacting backfill with rubber tired tractor.



Figure 13. Refilling trench with compressible material.

maximum density obtained by AASHTO Method T99. After the trench had been filled loosely, it was blanketed with a foot of silty clay bulldozed from the uphill-side of the cut. The settlement plates were then installed, and the remainder of the embankment was constructed in the usual manner. Silty clay material from a large cut at an underpass structure some 1,100 feet to the west was used in the first 23 to 25 feet of embankment above the pipe. Compaction was by self-propelled scraper haul traffic and crawler-pulled sheepsfoot rollers.

Results of density tests of samples taken near the springlines, near the top of the pipe, and at approximately five-foot increments of fill height varied from 97.1 to 105.1 percent of the maximum density obtained by AASHTO Method T99. The percent of moisture as determined by the same method varied from 46 to 114 percent of the optimum moisture content. Borings taken near each of the three transverse instrumentation locations at completion of the embankment indicated that the moisture content varied from 14 to 25 percent, and unconfined compressive strengths varied from 0.9 to 3.8 tons per square foot.

FIELD TEST RESULTS

Collection of pressure, settlement, and deformation data was begun when the height of fill above top of pipe was 2.5 feet. Data were recorded at approximately four-foot intervals of fill height until the embankment was completed. After the completion of construction in October 1961, complete sets of data were recorded in May 1962, and September 1962. Pressure readings were recorded in June 1963; however, settlement data were not collected at this time because of difficulty in locating the settlement rods.

In September 1967, a final attempt was made to collect a complete set of data

to determine how much change had taken place in the measured parameters in five years. Considerable effort was required to relocate all of the pressure cell lines and settlement pipes since some of the pressure lines and all of the settlement pipes were buried. Eventually, however, all of the lines and pipes were located and readings were made. Unfortunately, many of the reference points used to measure the pipe deformation were either missing or so badly corroded that measurement of the pipe deformation was not possible. Because elevations of the pipe invert were not taken at this time, a direct computation of the settlement ratio could not be made.

Since the last complete set of reliable settlement data was collected in September 1962, the settlement and pressure data were analyzed in this report only for the 500 days from May 1, 1961, to September 12, 1962. Data collected beyond this period, although not complete, indicate that little change took place in the settlement ratio or the soil pressures acting on the pipe.

Settlement Ratio

When designing a conduit for the induced trench condition, it is difficult to accurately predetermine the settlement ratio for a specific case. Ordinarily this ratio is determined empirically from observations of the behavior of culverts under embankments. Therefore, the determination of the settlement ratio for the induced trench was considered to be the primary objective of this study.

Since the induced trench insures that the column of soil over the culvert will settle more than the adjacent compacted soil, the settlement ratio for the induced trench will always be a negative quantity. In the absence of reliable data confirming the probable range of values of the settlement ratio for the induced trench, the ratio is currently assumed to lie between -0.3 and -0.5.

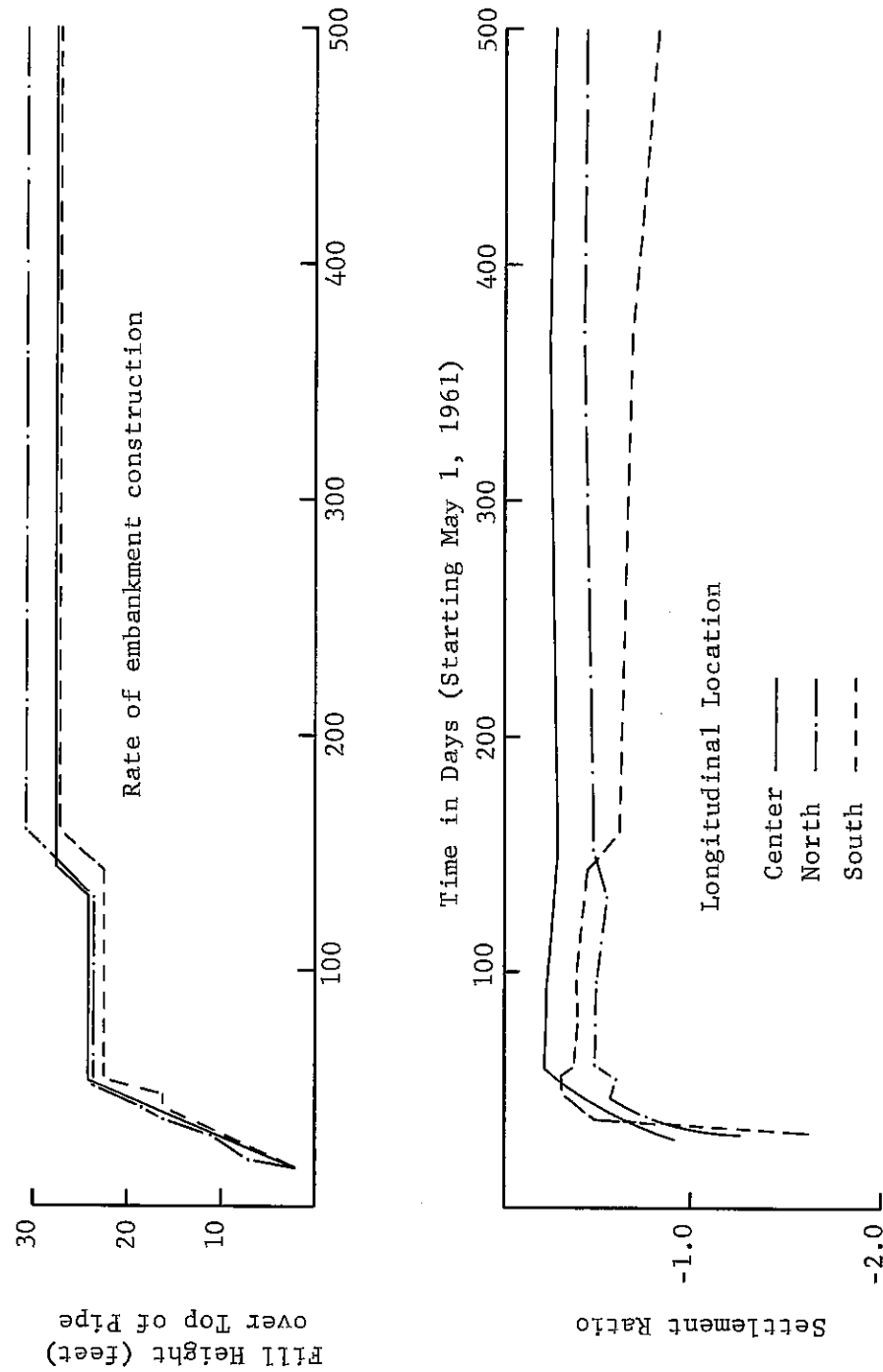


Figure 14. Settlement ratio vs. time.

west side plates settled different amounts (Figures 15 through 17). The magnitude of the settlement of the west plates is fairly consistent at the center and the south locations but is about 0.26 foot less at the north location after 500 days. The magnitude of the settlement of the east plates varied from 0.85 at the north location to 0.81 at the center location and 0.52 at the south location after 500 days. The variation in settlement of the side plates at the three locations possibly was caused by differences in the natural soil deposits on the uphill and downhill shoulders of the cut as previously described in the construction section of this report.

$(s_d + s_f + d_c)$ = settlement of critical plane

The measured settlement of the center plate located at the top of the trench directly over the culvert centerline was used as the total settlement of the critical plane. The settlement was consistent at the north and center locations but was considerably less at the south location (Figures 15 through 17). The variation in settlement is possibly partly due to the varying amount of fill over the different plate locations. The final amount of fill varies from a maximum of 30.5 feet at the north location to a minimum of 27.5 feet at the south location.

Measurements indicate unreasonably that the west plate at the south location settled more than the center plate. Since the magnitude of the settlement indicated for the west plate appears to be the one in error, only the settlement of the east plate was used in calculating the settlement ratio at the south location.

s_f = settlement of the pipe invert

The pipe invert settlement was consistent at all three locations

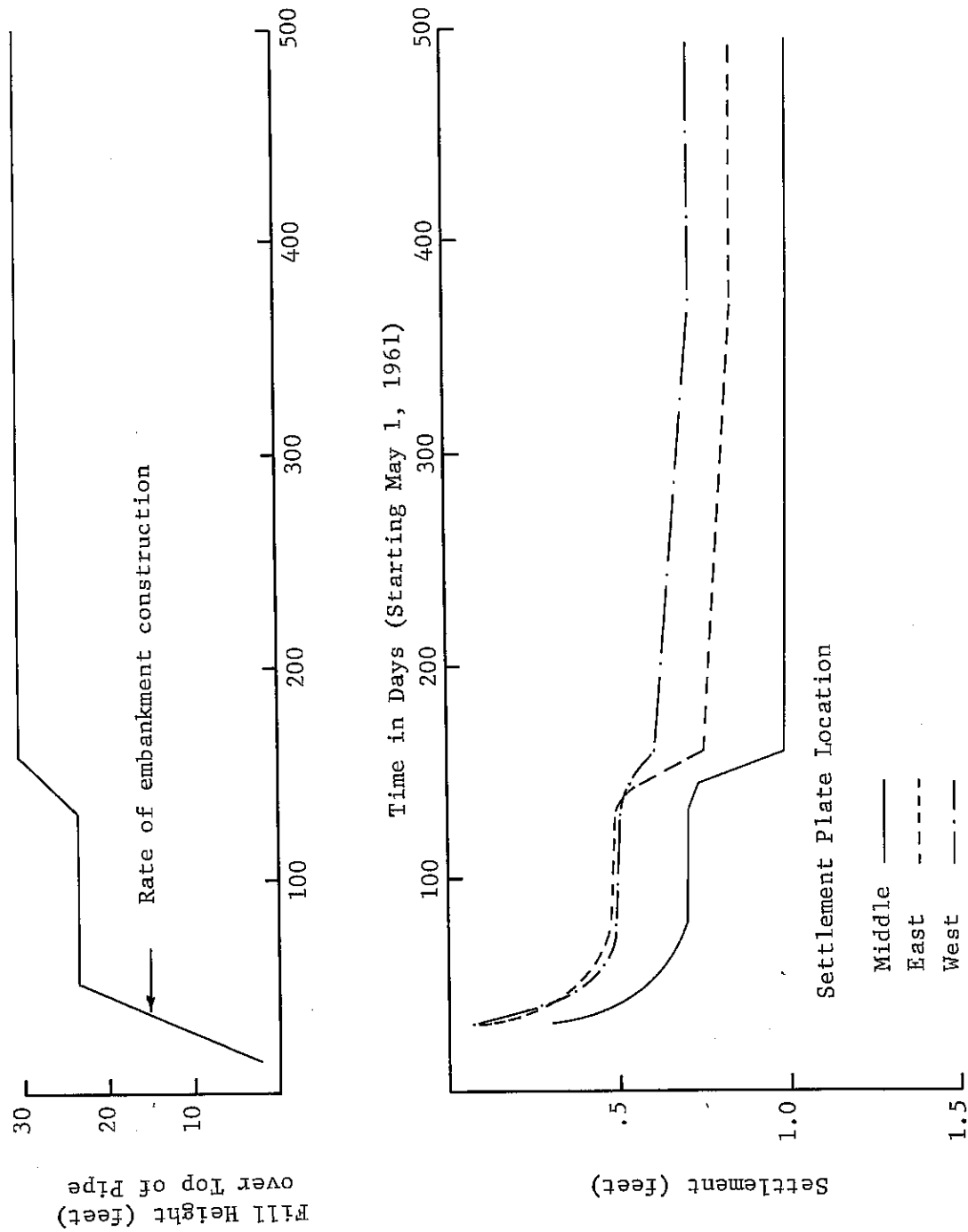


Figure 15. Settlement vs. time at north location.

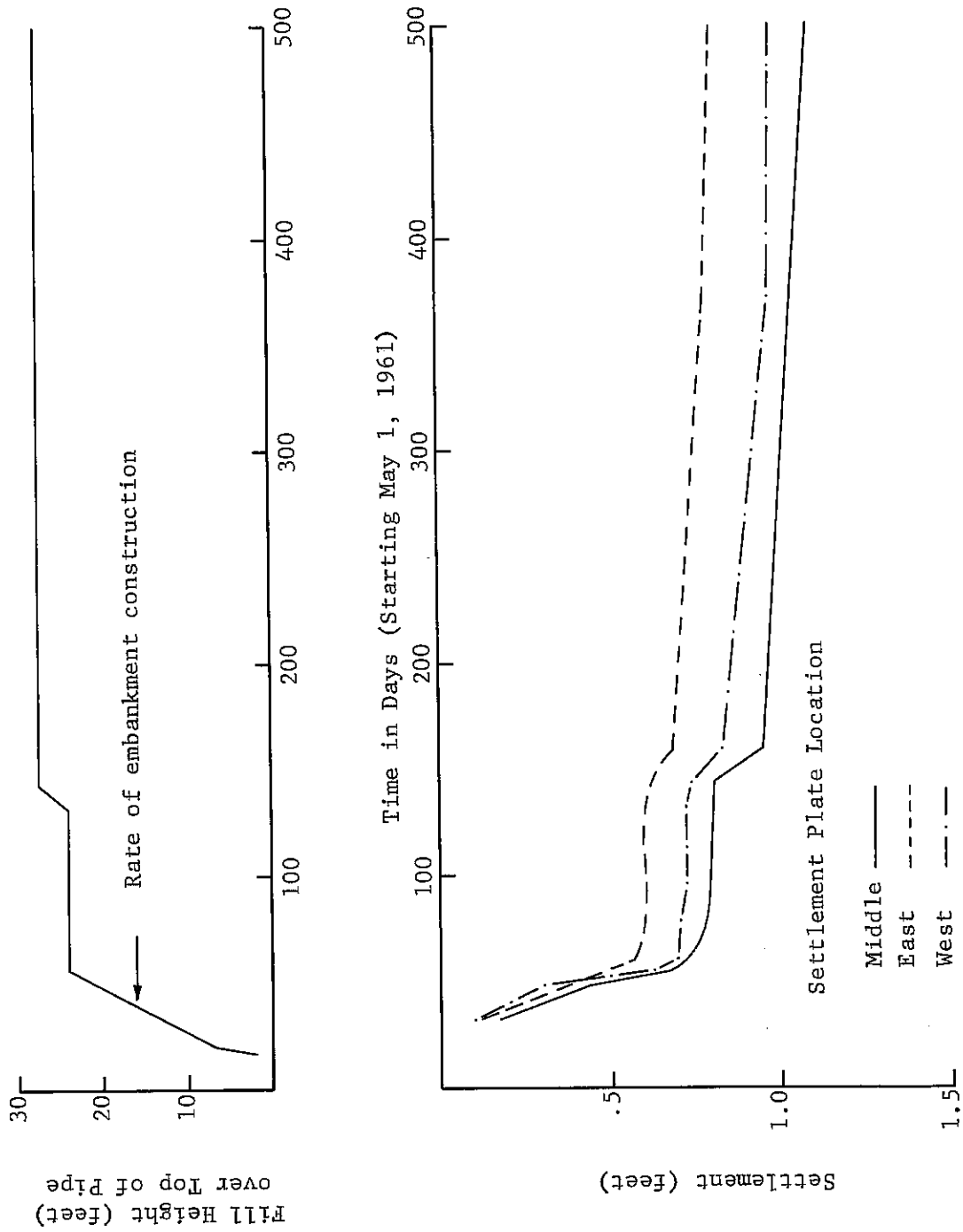


Figure 16. Settlement vs. time at center location.

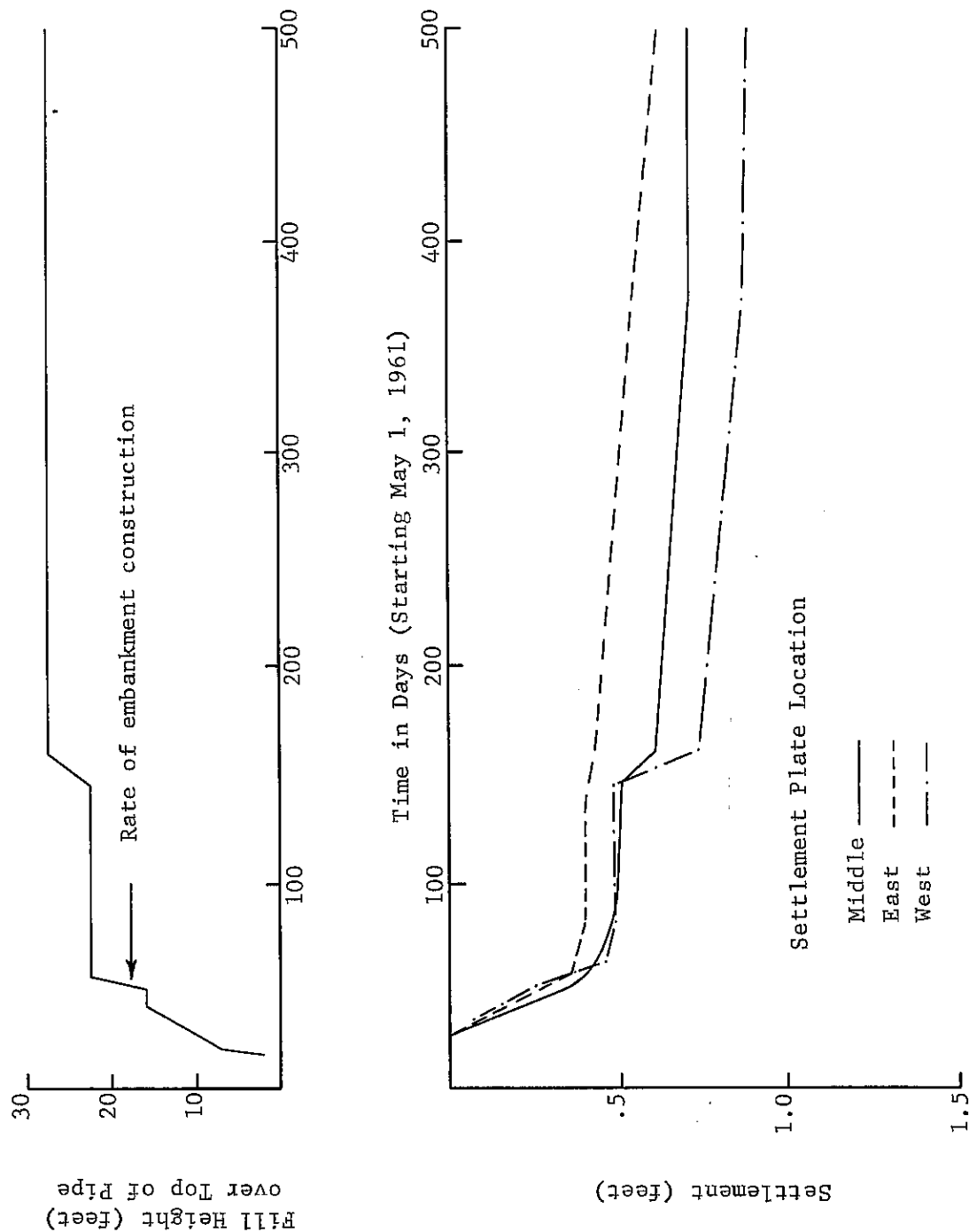


Figure 17. Settlement vs. time at south location.

as shown in Figure 18. The average magnitude of the settlement after 500 days was approximately 0.4 foot.

d_c = deformation of culvert pipe

The inside vertical diameter of the conduit decreased an average of about 0.010 foot after 500 days (Figure 19). The erratic change in pipe deformation during the construction of the embankment is possibly due to temperature changes within the pipe and not due to changes in load. However, data were not collected during this research to confirm the effect of temperature change on the pipe.

In addition to measurements of the change in vertical pipe diameter, changes in the horizontal diameter and each diameter at 45° from the vertical were measured. The indicated decrease in all diameters of about 0.01 to 0.02 feet does not appear to be consistent with the loads measured on the sides of the pipe.

Except for the south location, where settlement data were not consistent with data collected at the north and center locations, the values for the settlement ratio were near the limits of the range of values formerly recommended for the induced trench. Although the values of the settlement ratio were erratic during the initial construction of the embankment, the values of the ratio leveled off to approximately -0.25 at the center location and -0.45 at the north location after 150 days. Empirical values that have been recommended lie within the range of -0.3 to -0.5.

Measured and Theoretical Loads on Culvert

Although the theory used to determine the loads on this type of conduit is considered reasonably accurate, the pressures acting on the top and the sides of

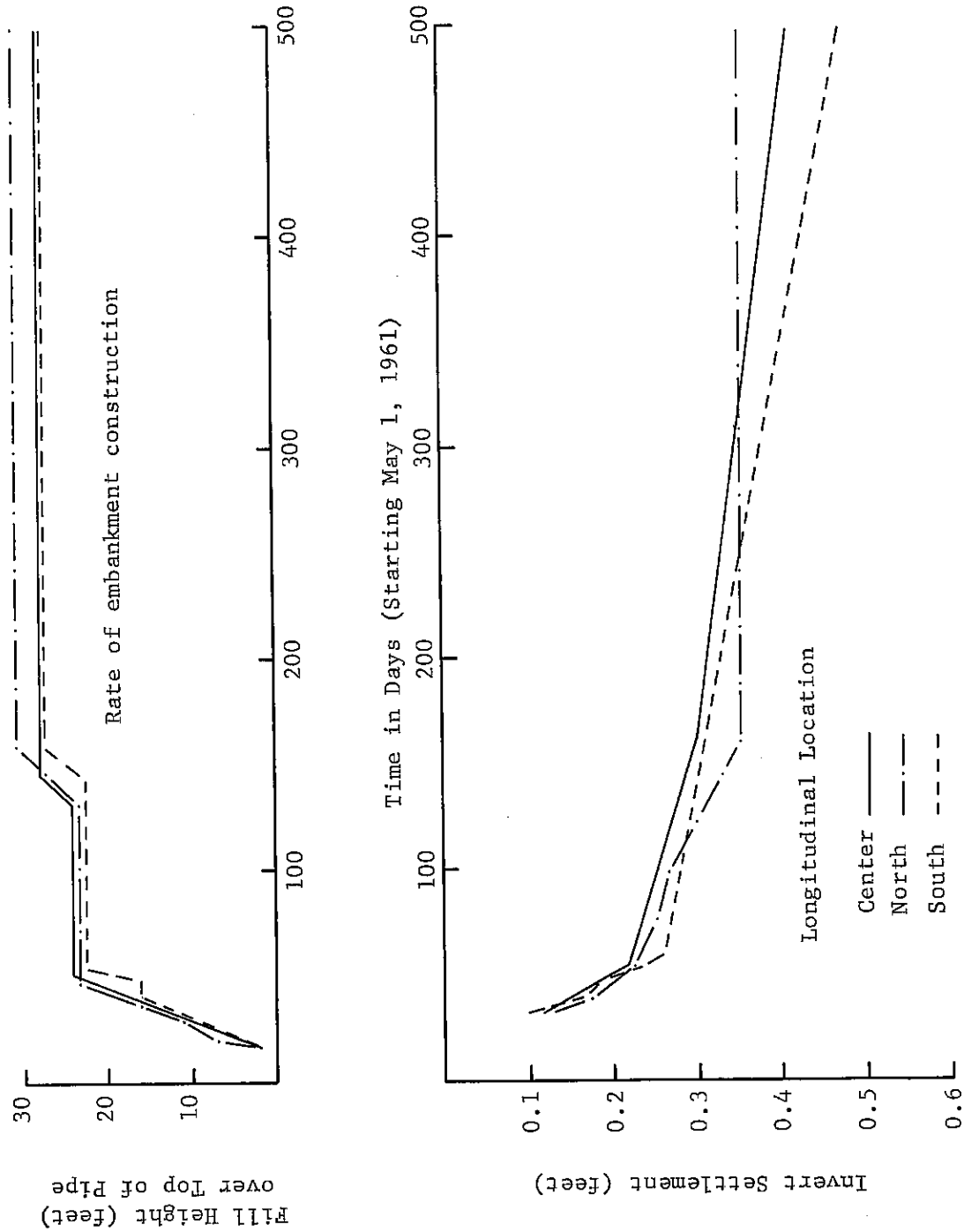


Figure 18. Invert settlement vs. time.

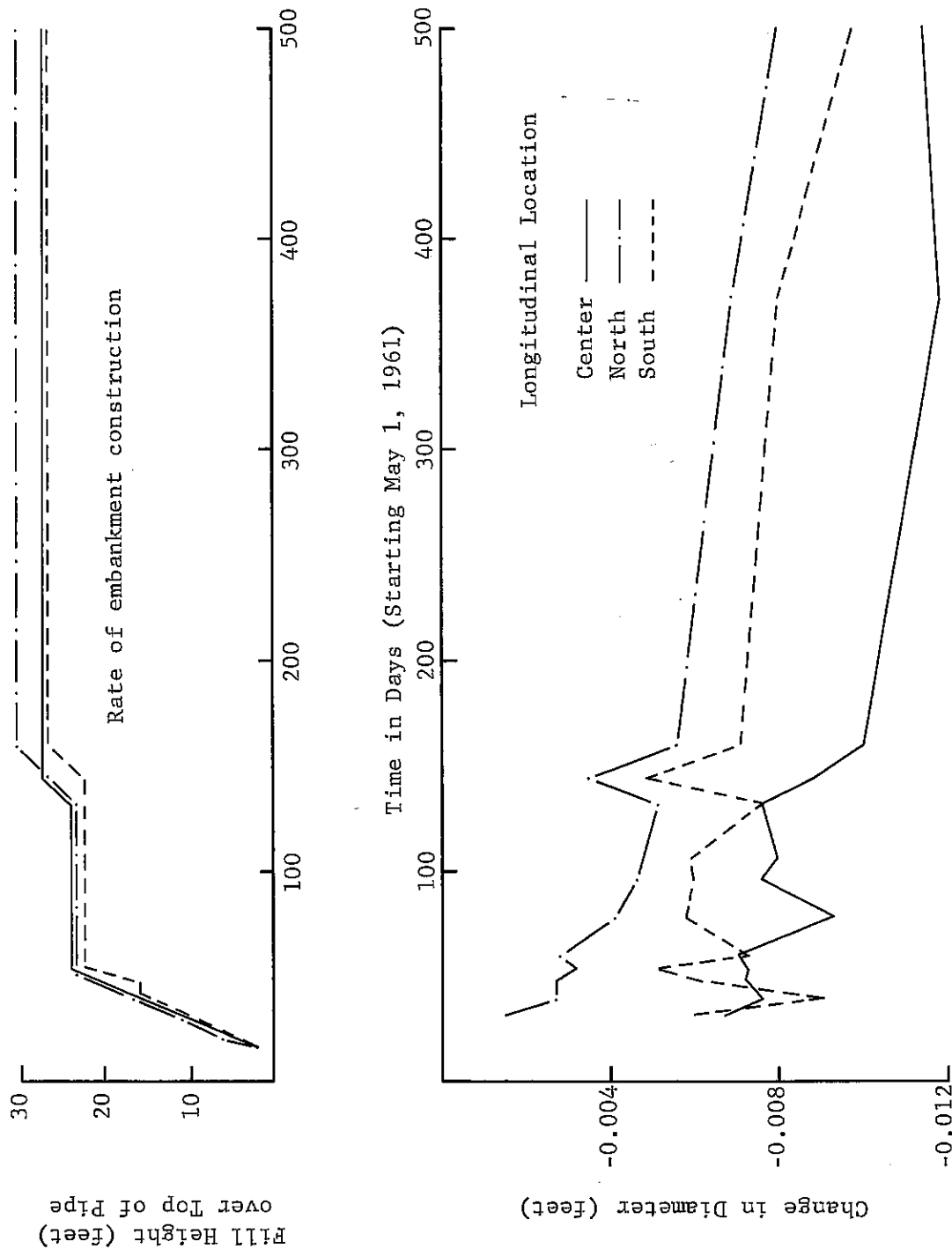


Figure 19. Change in vertical pipe diameter vs. time.

the culvert were measured during and after construction in order to confirm the theory. The recorded pressures, as plotted in Figures 20 through 22, indicate a large variation in pressure on the top cells during the first 150 days after construction began. The reason for the sharp drop in pressure after 60 days at all three locations is not apparent, especially since the fill height was constant during this period. It is possible that the heavy rainfall that occurred during the period may have had some effect on the pressures, although the degree of influence is not known.

After 150 days the pressures on the top cells at the north and center locations were fairly consistent and equal to about 7 pounds per square inch. The drop in pressure at the south location appears to indicate a possible malfunction in the pressure cell since it is not consistent with measurements at the other two locations.

The measured pressures at the side of the culvert as plotted in Figures 20 through 22 were in the order of 1 to 2 pounds per square inch. These values appear to be extremely low for this type of installation, although the arching action of the soil above the culvert could conceivably transmit a large proportion of the load to the sides of the ditch above the pressure cells. Also, it is possible that after the holes were excavated to install the pressure cells, dessication of the adjacent soil may have formed a hard inflexible crust in front of the cells which did not permit typical pressures to be transmitted to the cells.

The low recorded pressures also may have been caused by drying out of the AM-9 grout used to fill the spaces between the soil and the pressure cells. The grout may have hardened if the soil became dessicated. Literature from the manufacturer of the chemical grout indicates that the AM-9 gels shrink if they are allowed to dry. Although the shrinking process is understood to be reversible

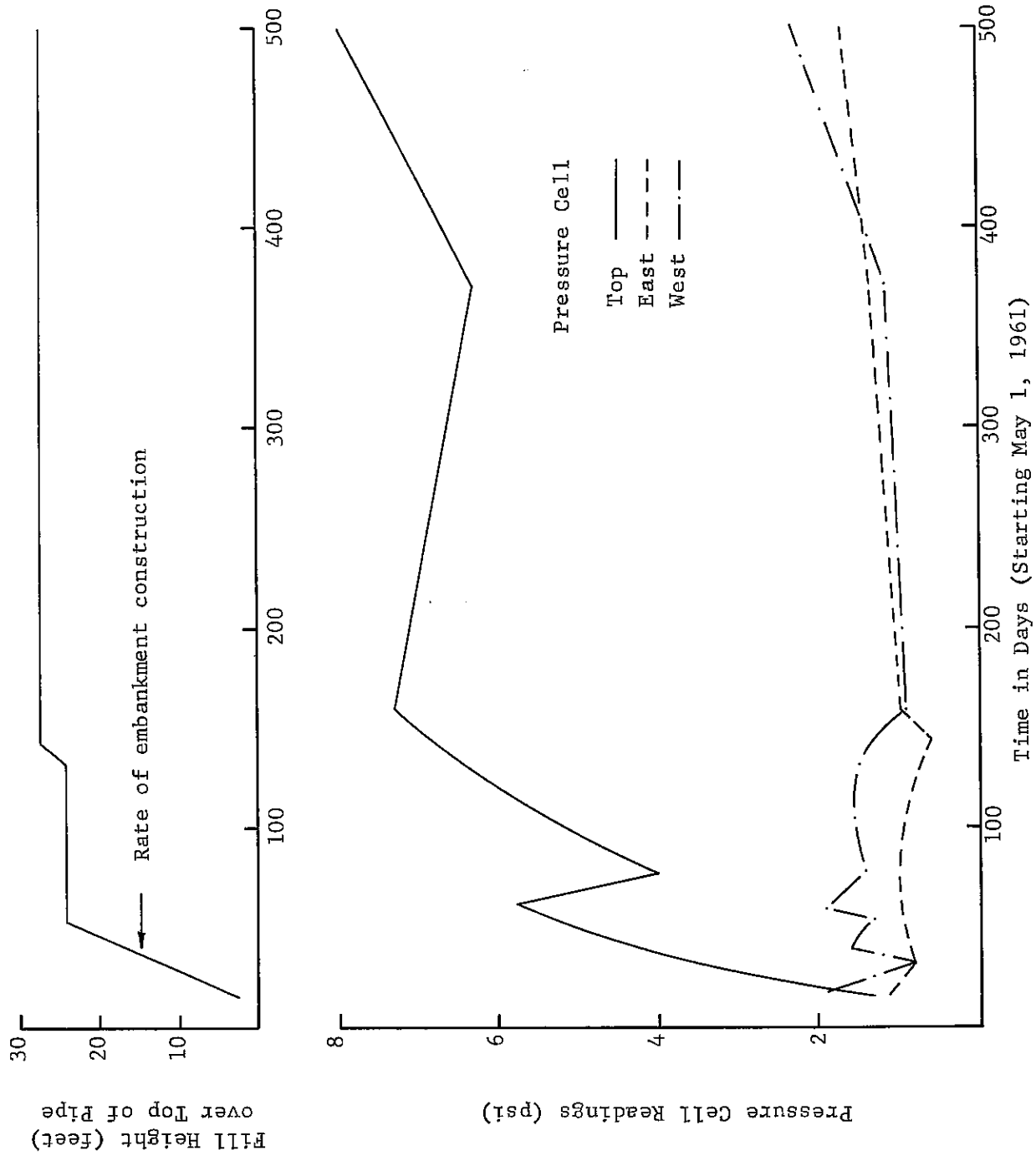


Figure 20. Pressure cell readings vs. time at north location.

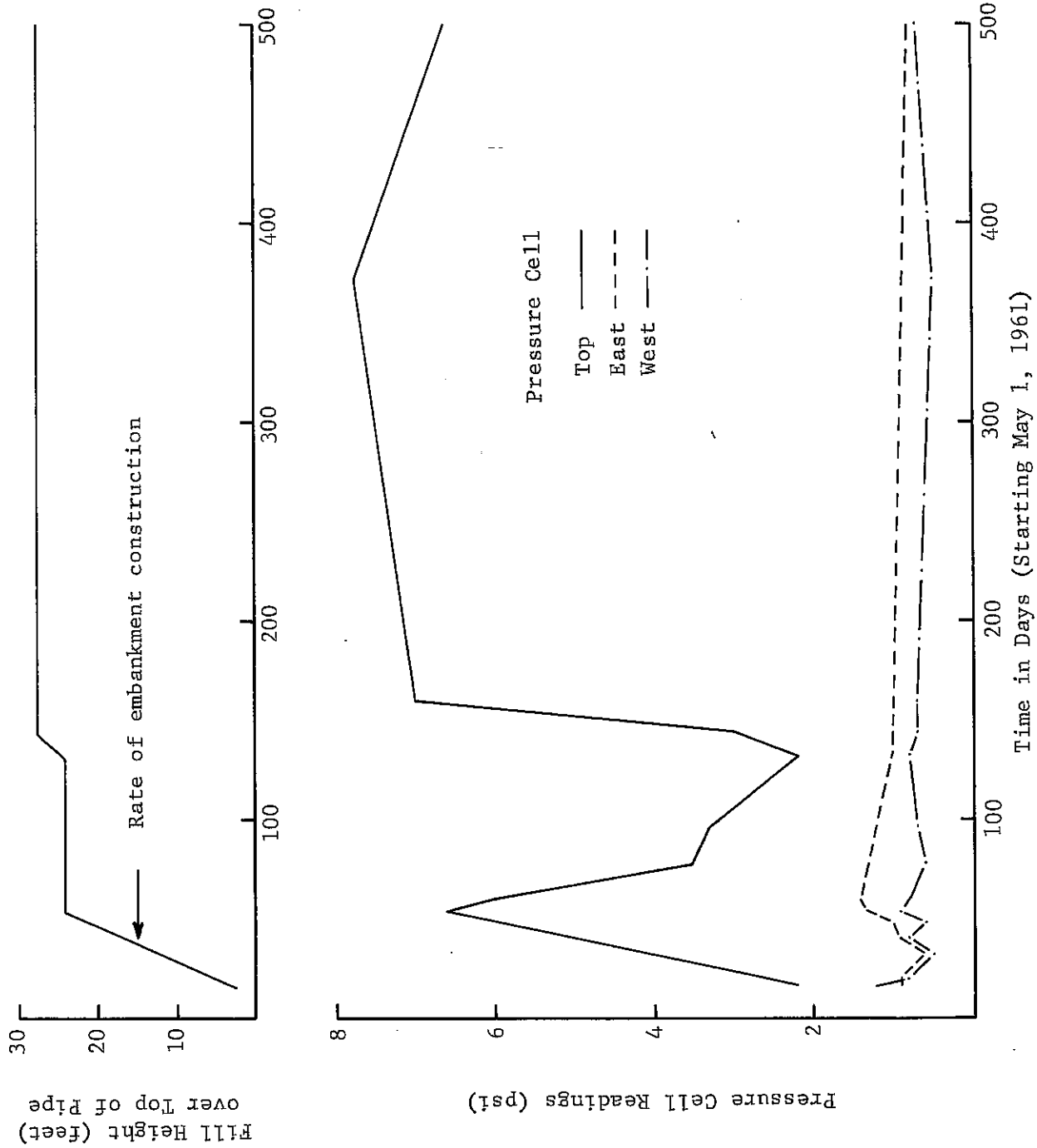


Figure 21. Pressure cell readings vs. time at center location.

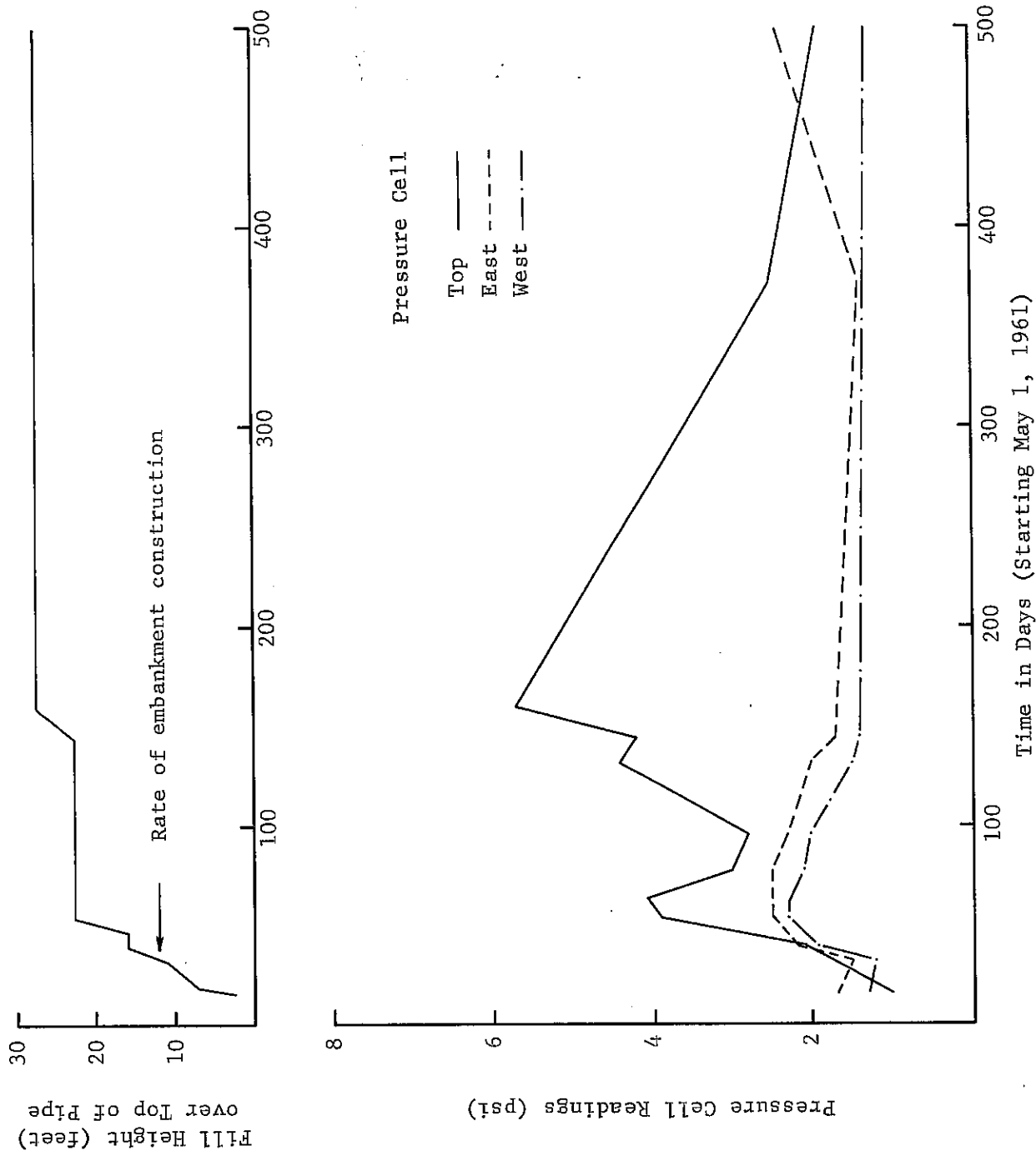


Figure 22. Pressure cell readings vs. time at south location.

with the addition of water, once the gel had dried, sufficient moisture may not have been present in the soil to swell the dry gel to its original shape.

The pressure cell readings taken in 1963 and in 1967 were consistent with the readings taken in September 1962, except for the west cell at the south location. The pressure recorded at this cell increased from 1.0 psi in 1963 to 6.5 psi in 1967. Clogging of the lines is believed to be responsible for the relatively large increase in the pressure recorded at this location.

In order to compare the theoretical loads which would act on this conduit with actual measured loads, the measured pressures were converted to load per linear foot of pipe. The measured loads corresponding to the rate of embankment construction are plotted as Curve 1 in Figures 23 through 25.

Using an assumed unit weight of soil of 120 pounds per cubic foot, the theoretical loads which would act on the induced trench installation based on Marston's formula are plotted as Curve 2 in Figures 23 through 25.

Neglecting the curves for the south location which show the inherent inconsistencies of the pressure charts, a comparison of Curves 1 and 2 at the north and center locations indicate that the measured loads were not greater than 50 percent of the theoretical loads after the embankment was completed.

In addition to a comparison of the theoretical and measured loads acting on the induced trench, Figures 23 through 25 also include as Curves 3 and 4 the theoretical loads which would act on this culvert if the induced trench method of construction were not used. Two hypothetical conditions were used for comparison with the induced trench installation. Because the depth of the trench varied from about 4 to 8 feet along the length of the culvert, Cases I and II illustrated in Figure 26 represent the approximate range in trench depth and were used to estimate the range in loads acting along the length of the culvert.

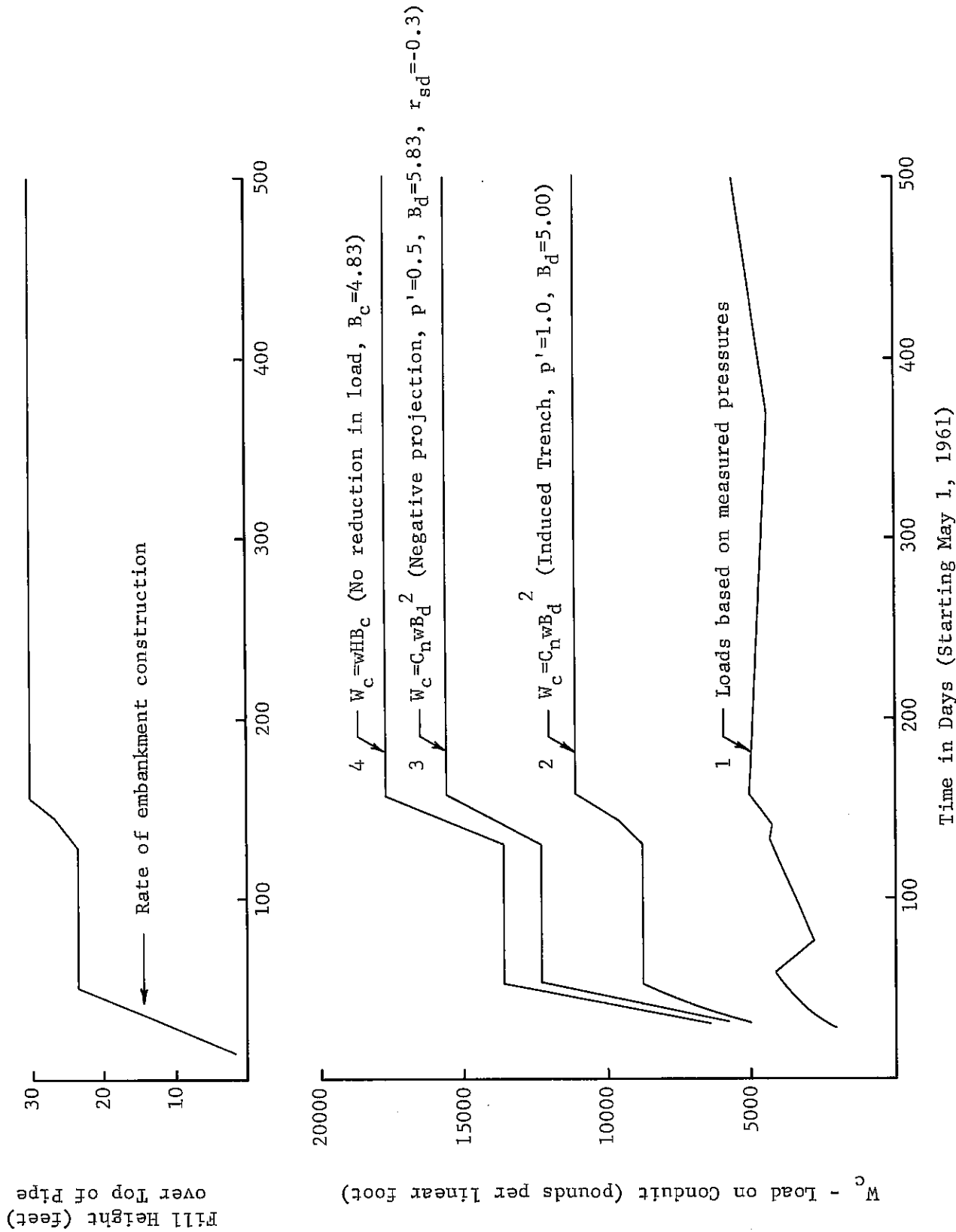


Figure 23. Theoretical and measured vertical loads at north location.

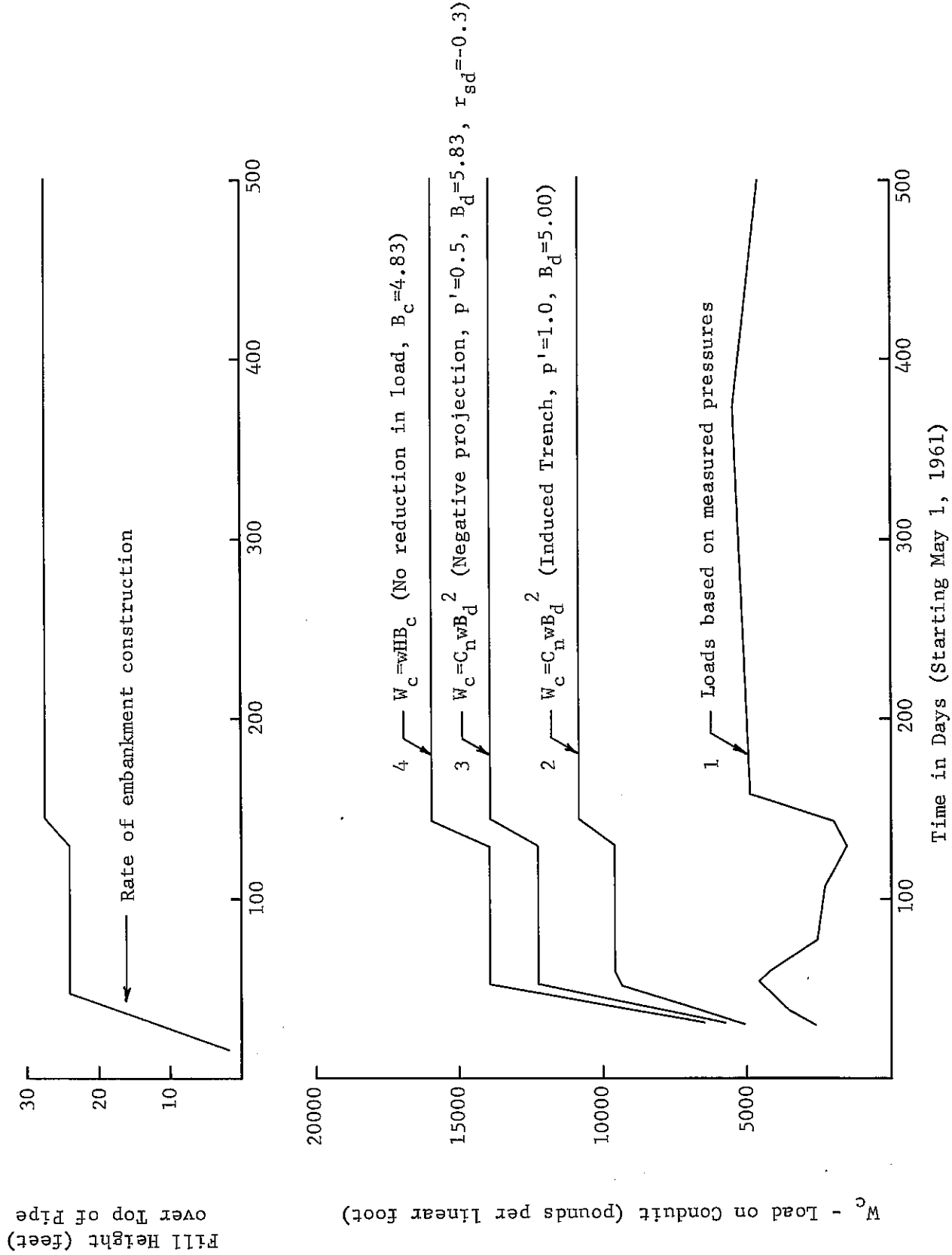


Figure 24. Theoretical and measured vertical loads at center location.

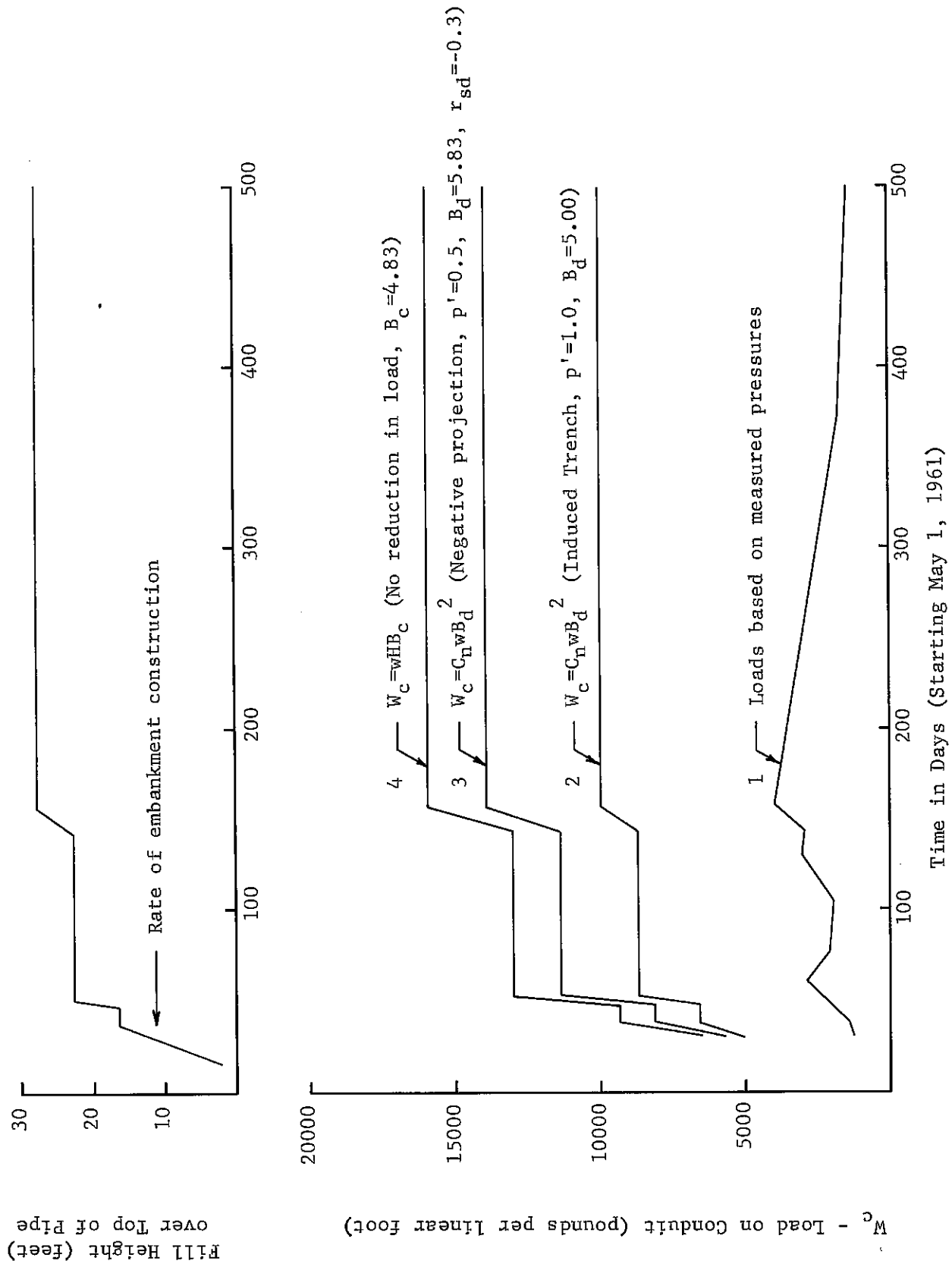


Figure 25. Theoretical and measured vertical loads at south location.

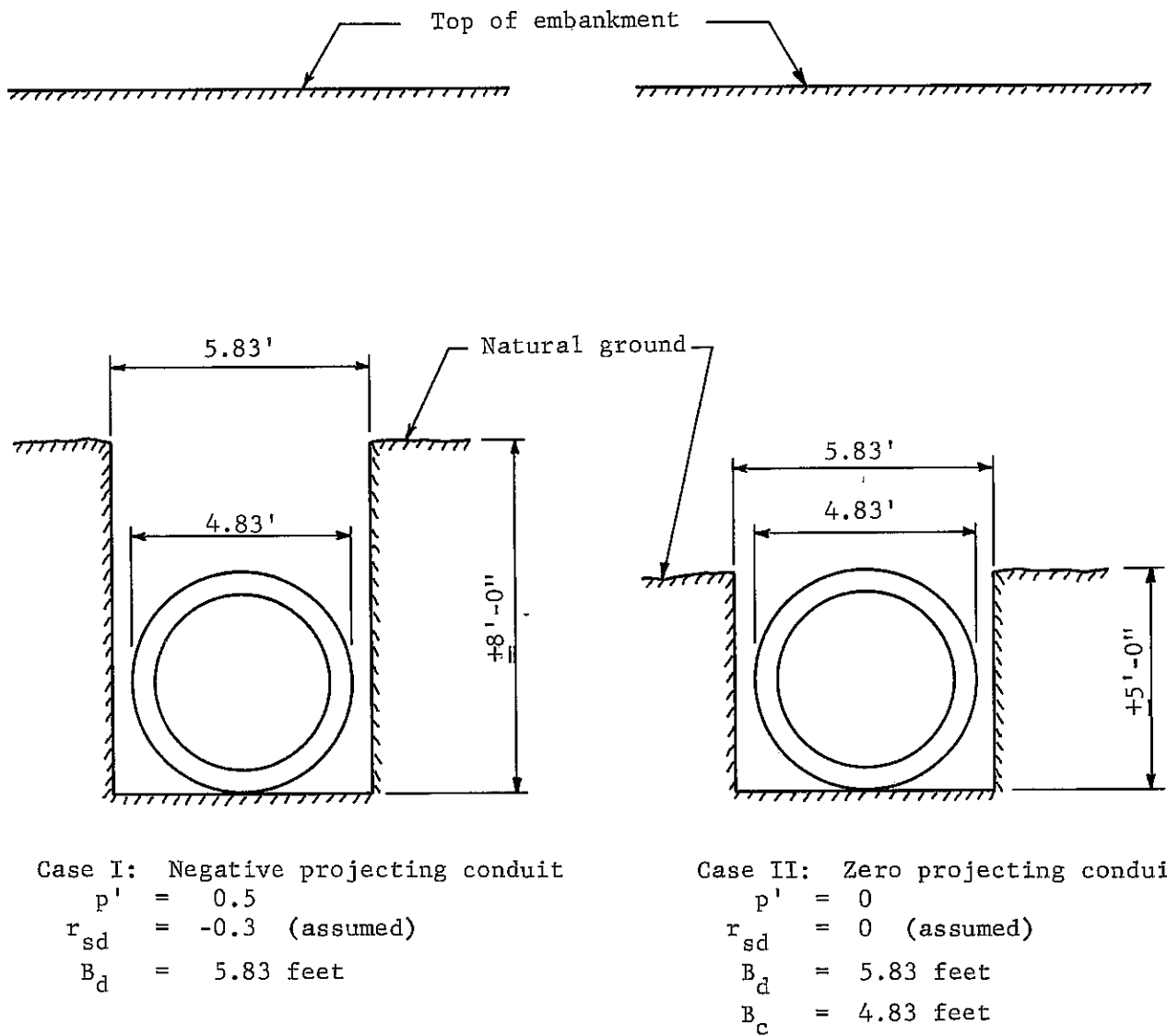


Figure 26. Limits of culvert projection without induced trench.

In Case I the width of the trench was assumed equal to the width of the conduit plus 1 foot or 5.83 feet, and the depth of the trench below natural ground was assumed equal to 8 feet. Since the top of the pipe is placed below natural ground, this case corresponds to a negative projecting conduit with a projection ratio of about 0.5. The recommended range of values for the settlement ratio for a negative projecting conduit and an induced trench is about the same. Assuming a value for the settlement ratio of -0.3, the theoretical loads on the culvert were computed by Marston's formula and plotted as Curve 3 in Figures 23 through 25.

For Case II the top of the conduit was assumed to be level with natural ground which would result in a projection ratio of zero and correspond to a trench depth of about 5 feet. Assuming that no relative movement would take place between the soil prism above the pipe and the adjacent soil, i.e., $r_{sd}=0$, there would be no reduction in load on the conduit, and it would support the total weight of the above column of soil. In Figures 23 through 25 this situation is represented by Curve 4.

The unit weight of the fill material above the culvert for Curves 2, 3, and 4 was assumed to be 120 pounds per cubic foot. In comparing Curves 3 and 4 with Curve 2, the advantage of using the induced trench method of construction at this installation is apparent.

CONCLUSIONS

The settlement ratios for the induced trench method of installation as determined by this research project correlate well with the range of values that have been recommended by others. Empirical values of the settlement ratio recommended for use with the induced trench range from -0.3 to -0.5. After initial variations during construction of the induced trench installation, values of the settlement

ratio at two of the three locations where settlement measurements were made ranged from -0.25 to -0.45. At the third location a settlement ratio of -0.8 was recorded which is considered unreliable because of discrepancies in the settlement data.

No change from current recommendations regarding values to be assumed for the settlement ratio is proposed on the basis of the research described in this report. Before reaching definite conclusions concerning the precise value of the settlement ratio for this type of construction, other similar tests must be conducted on culverts of different sizes placed under various fill heights.

Although the settlement ratio of the induced trench and a negative projecting conduit may have similar values, a significant difference in the applied loads on the conduit can occur due to the difference in trench widths for the two types of installations. The trench width of the negative projecting conduit must by nature be wider than the pipe to allow room for construction, while the induced trench width is usually equal to the width of the pipe. The larger trench width of the negative projecting conduit results in an appreciable difference in load as determined by the theoretical formula $W_c = C_n W B_d^2$, since the load is directly proportional to the square of the trench width. For this reason a substantial decrease in the loads on the culvert can result from the construction of the induced trench above the conduit.

At this installation there has been no indication of any settlement of pavement over the top of the induced trench. This indicates that a plane of equal settlement has formed beneath the top of the embankment.

At all three locations where pressure cells were located at the top and sides of the culvert, the measured pressures appeared to be low for this type of installation. After initial variations, loads based on measured pressures on top of the

culvert at the north and center locations were at a fairly consistent level of about 5000 pounds per linear foot. This represents a load level equal to about 50 percent of the theoretical loads. The sharp drop in load after initial variations at the south location apparently is due to a malfunction of the pressure cell since the load is not consistent with measurements at the other two locations.

The measured pressures of 1 to 2 psi at the sides of the pipe at all three locations also appear to be low for this type of installation, although the arching action of the soil above the pipe could conceivably transmit a large portion of the load to the sides of the ditch above the lateral pressure cells. Also, it is possible that after the holes were excavated to install the pressure cells, desiccation of the adjacent soil may have formed a hard inflexible crust in front of the cells which did not permit typical pressures to be transmitted.

IMPLEMENTATION

Although the loads based on measured pressures were fairly consistent at two of the three instrumented locations, much more data from this type of installation are required before final conclusions are drawn on the accuracy of the theory. At the present time it is recommended that the theory, which appears to be conservative, continue to be used without adjustment.

APPENDIX A

SPECIFICATIONS FOR EXPERIMENTAL INDUCED TRENCH INSTALLATION

1. Bedding and Installation of Pipe

- (a) The foundation shall be prepared and the pipe bedded in accordance with the provisions of Article 58.4 of the 1958 Standard Specifications entitled "Preparation of Foundation," except that a sand bed that will assume a minimum three-inch thickness when compacted by the weight of the pipe shall be placed under the pipe in accordance with the Special Provisions for the project.
- (b) The pipe shall be installed in accordance with the provisions of Article 58.5 of the 1958 Standard Specifications entitled "Laying Pipe."
- (c) Profile elevations of the culvert pipe shall be run following installation.

2. Backfilling and Instrumentation

- (a) Embankment or backfill over the pipe shall be constructed in accordance with the provisions of Article 58.7 of the 1958 Standard Specifications entitled "Placing Embankment or Backfill," except that sand shall be placed simultaneously to a width of approximately six inches greater than the outside diameter of the pipe on each side to the elevation of the centerline of the pipe (simultaneously, in this case, meaning that the difference in elevation of the sand on opposite sides of the pipe shall not exceed six inches at any time during the process of placing the embankment or backfill) as provided by the Special Provisions for the project. The remainder of the material above the elevation of the pipe centerline and up to 1' -0" above the top of the pipe centerline and up to 1' -0" above the top of the pipe may be any regularly acceptable

backfill or embankment material.

- (b) When placement and compaction of embankment or backfill material has reached an elevation of 1'-0" over the top of the pipe, it will be necessary to hold up further placement for placing of pressure cells. These will be placed at three locations under the high section of the fill, one on the roadway centerline and one approximately under each shoulder.
- (c) It will be desirable to determine the density and moisture content of the earth backfill or embankment material on both sides of the pipe at two or three locations at the plane of the centerline of the pipe and at the plane of the top of the pipe. Samples of the material should be taken for moisture-density tests and classification tests.
- (d) To place the pressure cells, a hole will be dug down by hand to the springline on each side of the pipe and to the top of the pipe on the centerline of the culvert.
- (e) Pressure cells will be cemented to the pipe and leads run through holes to the pipe interior.
- (f) Space around the cells will then be filled with an AM-9 grout in proper proportions to prevent flow of the grout into the surrounding soil. The remainder of the holes will be backfilled and compacted.
- (g) Placing of the roadway embankment over the pipe will then proceed in the normal manner to an elevation of not less than 6'-0" above the top of the pipe.

3. Constructing the Imperfect Trench

- (a) With the embankment constructed to an elevation of not less than 6'-0"

above the top of the pipe, a trench shall be excavated 5'-0" wide and centered directly over the pipe to 1'-0" above the top of the pipe. The trench shall extend in each direction from the roadway centerline to points where the embankment cover over the top of the pipe approximates six feet. Sides of the trench should be kept vertical within a tolerance of six inches.

- (b) The trench shall be refilled with topsoil containing a moderate amount of vegetation, placed in the loosest possible condition. Soil and vegetation stripped prior to embankment construction will be satisfactory for this purpose. In no case should the loose soil have a relative density greater than approximately 75 percent. Samples of this material should be taken and tested to determine its classification as well as moisture and density.
- (c) Settlement plates will then be installed in the approximate same locations as the pressure cells. One plate will be placed on the loose fill directly over the culvert centerline. One plate will also be installed on the compacted embankment fill at each side of the loosely filled trench approximately 5'-0" out from the culvert centerline, making a total of three at each location.

4. Observations

- (a) At about every 5'-0" increment of fill height, readings of pressure cells will be taken. At the same time the elevation of the settlement plates and the pipe invert will be taken.
- (b) These observations will be continued until fill has been completed and for as long after as significant readings can be obtained.
- (c) Moisture-density tests should also be made on the embankment over the

culvert at about 5-ft. increments of fill height. If the soil classification is uncertain, samples should be taken for classification tests.

- (d) Laboratory tests of the soil should be made when convenient.
- (e) Extensive photographic record of pipe bedding and other features of the installation should be made.
- (f) Vertical and horizontal pipe diameter change measurements should also be made at intervals indicated in item 4(a).

5. Responsibility

- (a) Placing of the pressure cells, settlement plates and other necessary instrumentation will be the responsibility of the American Concrete Pipe Association.
- (b) Bedding and laying the pipe, placing the backfill and the embankment, constructing and backfilling the Imperfect Trench will be the responsibility of Peter Kiewit and Sons Co.
- (c) It will also be the responsibility of Peter Kiewit and Sons Co. to avoid damaging the instrumentation, particularly vertical rods extending through the fill from the settlement plates.
- (d) The Bureau of Research and Planning of the Illinois Division of Highways will provide an observer to verify the procedures used and the readings taken.
- (e) District 2 of the Illinois Division of Highways will be responsible for soil sampling and testing.